SOIL TEMPERATURES AND FLUXES : IMPLICATIONS FOR A VOLCANO STRUCTURE.
EXAMPLES OF MATTHEWS AND HUNTER (S.W. PACIFIC)

Alain TABBAGH , Département de Géophysique appliquée Université Paris 6 et Centre de Recherches Géophysiques, C.N.R.S., Garchy 58150 France.
Michel LARDY, O.R.S.T.O.M., B.P.5, Nouméa Cedex, Nouvelle Calédonie.

ABSTRACT

Temperature is one of the easiest parameter to be acquired on a remote volcano and transmitted via the CTIV (Centre de téléobservation informatisée des volcans). When recorded along vertical profiles, soil temperatures allow the calculation of the heat flux, of it's transient variations and also of it's steady value over an annual cycle. These data can be a valuable indicator for the presence of heat sources inside the volcano. Since september 1986, one such profile has been recorded on Matthews, and since september 1988 on Hunter. On both volcanoes neither unsteady nor steady abnormal flux of heat has been observed. This result, which differs from what had been obtained on Mount Etna, can be used in order to define upper limits for the depth or magnitude of possible sources of heat. This type of flux measurements would be very interesting if undertaken on a series of locations on the same edifice, in order to obtain a map of flux differences which could be used for a better description of the internal structure of volcanoes.

* * *
* *

The energy balance at the surface of a volcano is an important parameter for characterising its mid term activity. In "hot areas", the transfer corresponds to a convective flow of gas through the permeable surperfical layers ; but eslewhere, the conductive heat flux may contain an upward term corresponding to an energy release (Tabbagh & Trézéguet 1987). Temperature measurements at several points on shallow vertical profiles allow us to determine the flux. These measurements are quite easy to install and to transmit ; the coupling with satellite borne systems, such as Argos, offers now the possibility to record the data evry vhere on the Earth over periods of time that can easily exceed on annual cycle. The recording of data is done in Garchy by the "Centre de téléobservation informatisée des volcans".

The principle of flux calculations is the following : starting from temperature measurements we determine the flux at the surface Q_o (t) and the flux at the lower point Q_o (t). Several methods can be used : the finite element one, where each element is a vertical portion of the profile limited by two points of temperature measurement, or analytical ones, for example by decomposing the time variation in a series of step functions. These calculations need the knowledge of the transfer parameters, soil thermal properties and, in the case of convection, volumetric flow rate. If the record is sufficiently long we can determine both the steady values of the flux and its transient variations, and define the value of the upward part of these fluxes corresponding to heat release from the inner of the volcano.

This method of flux determination was first applied on Etna mount and we established at Torre del Filosofo station that the steady flux of internal origin varied significantly : - 720 mw/m^2 (minus means upward) during the 1982-1983 period, - 1.4 to 2.0 w/m^2 during the 1984-1986 period.

In the experiment of remote monitoring on Matthews and Hunter, undertaken under the leadership of O.R.S.T.O.M. Nouméa geophysical group, one temperature profile was installed on each volcano and we present her the results obtained on Matthews for the period October 1986-September 1988 and on Hunter for the period October 1988-September 1989.

On Matthews the temperature profile was located (figure 1) on T.S. point on the inner side of the rim surrounding the north-west lava flow (Maillet & al, 1986). Temperature measurements were made at 3, 30, 60 and 120 cm. The thermal properties of the soil was measured on samples in the laboratory, by following the time evolution after saturation of the compacted samples we obtained 0.63 w/m/k for the conductivity and 0.76 10^{-6} m^2/s for the diffusivity. The unsteady fluxes obtained for the first annual cycle using both the finite element method and the analytical calculation for a conduction transfer only are presented on figure 2. There is no high value suggesting a possible convection, the variations are more important at ground surface than at 1.2 depth, when calculating the correlation function between the flux at 0 m and the flux at 1.2 m one oberves a maximum for a time delay of six days in good agreement with the diffusivity value. The situation is the same for the second annual cycle and one can conclude that all the fluxes variations observed originate in extermal climatic variations and diffuse by conduction into the ground.

When calculating the steady flux at 1.2 m for the first annual cycle one obtains - 0.03 w/m^2, a very small value, which is confirmed by an other small value of 0.005 w/m^2 for the second cycle. For evaluating these values we have to compare them to the low climatic variations obtained in the same climatic areas. By using the data acquired by J.P. Brun at Noumea meteorological station during the interval March 1978- December 1980 we obtained -. 141 w/m^2. We can conclude then that the values obtained on the volcano stay in the range of the "climatic noise" and that we have to condider that there is no abnormal steady flux at this location on Matthews.

On Hunter the soil temperature profile was installed in the saddle 50 m at the north of the southern summit (figure 3), temperature measurements were made at 30, 60, 90 and 120 cm. Thermal properties were measured in the laboratory on four different samples corresponding to each depth, they were uniform, we had 1 w/m/k for the conductivity and 0.5 10^{-6} m^2/s for the diffusivity. The unsteady variations are very similar to those obtained on Matthews and correspond also tho the absence of convective flux (figure 4) and to the effect of external climatic transient variations diffusing downward.

When calculating the steady flux we obtained 0.155 W/m^2 which is again in the range of the long term climatic noise and correspond in fact to the absence of abnormal internal flux.

To the question, what can be deduced from the absence of internal steady flux on both volcanoes ? A first answer is to study the minimum distance and volume of several types of possible sources of heat. We calculated three simple models presenting the cooling of a neck (figure 5), the cooling of a magma pocket of spherical or sill shape (figures 5c and 5b) and also the effect of a magmatic chamber. The results of the differents calculations are presented on the following table.

Neck

$$\left.\begin{array}{l} t = 1.42\ 10^{9} s \\ \Gamma = 10^{-6}\ m^2/s \\ k = 2.5\ w/m/k \\ \theta o = 1000\ ^\circ c \\ z = 0 \\ r = 100\ m \\ a = 10\ m \end{array}\right\} \rightarrow \varphi = -\ 0.113\ w/m^2$$

Magma pocket

Sphere

$a = 10$, $h = 100$ m $\varphi = - 0.052$ w/m^2

$a = 50$, $h = 100$ m $\varphi = - 6.6$ w/m^2

$a = 50$, $h = 200$ m $\varphi = - 0.067$ w/m^2

Sill

$e = 10$ m $h = 60$ m $\varphi_3 = - 4.2$ w/m^2

$h = 100$ m $\varphi = - 2.21$ w/m^2

$h = 150$ m $\varphi = - 0.379$ w/m^2

$h = 200$ m $\varphi = - 0.023$ w/m^2

Magmatic chamber

Sphere

$a = 50$ m, $h = 500$ m $\varphi = - 1.00$ w/m^2

$a = 100$ m, $h = 1000$ m $\varphi = - 0.49$ w/m^2

$a = 50$ m, $h = 1000$ m $\varphi = - 0.25$ w/m^2

$a = 200$ m, $h = 2000$ m $\varphi = - 0.13$ w/m^2

For the first three cases we used a value of t equal to 45 ans, which corresponds to the last historical eruption of Matthews (Lardy & al, 1988). The magmatic chamber is considered as in place for a long time.

A distance of 100 m is sufficient to have a very small flux for the neck, it is the same for the magma pocket for a depth of 100 m if it is small (a = 10 m) or for a depth of 200 m if it is greater (a = 50 m). For a magmatic chamber at constant 1000°C temperature, a depth of 2 km is sufficient to explain the negligible surface flux.

One can conclude that the quasi-null steady flux values obtained allow to fix several limits to the possible internal structure of the volcano. But it would be far more interesting to have a series of such profiles on the same mount and not only one. If a net of temperature profils is used the long term climatic variation would be identical at all the points and the map of flux differences totaly free of this effect, would be of high value to study the internal structure of a mount or of an active zone.

Références

Lardy M. & Monzier M., 1986, - Rapport de mission sur l'installation de la station de volcano-sismologie sur le volcan Matthews ; Rapport 3-86, O.R.S.T.O.M. Nouméa 54 p.

Maillet P., Monzier M. & Lefèvre C., 1986, - Petrology of Matthews and Hunter volcanoes, south new Hebrides island arc (South-West Pacific) ; J. of Vol. and Geoth. Research, 30, 1-27.

Tabbagh A. & Trézéguet D., 1987, - Determination of sensible heat flux in volcanic areas from ground temperature measurements along vertical profiles : the case study of Mount Etna ; J.G.R., 92-B5, 3635-3644.

Fig. 1 Map of the Matthews volcano (after Monzier)

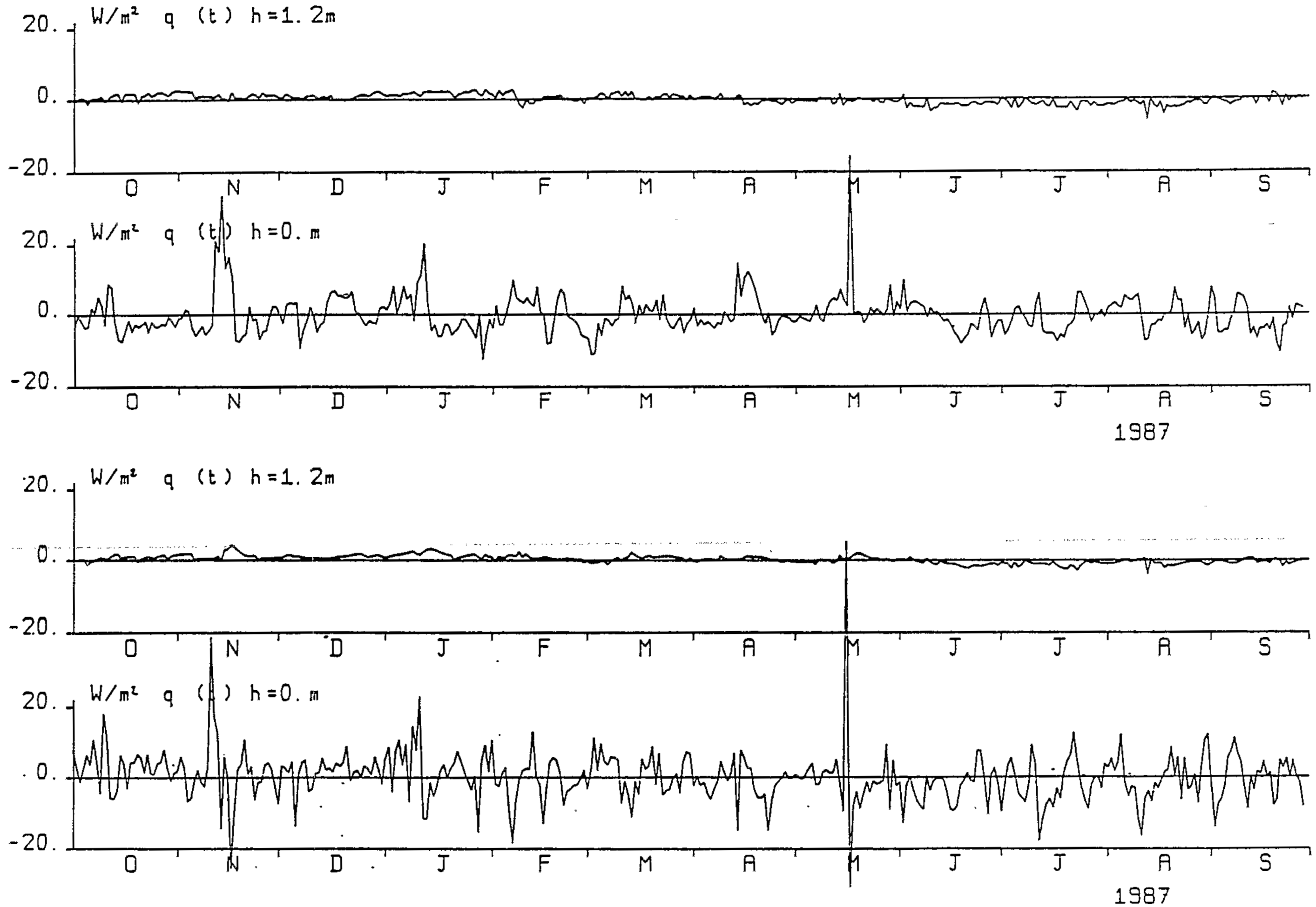

Figure 2 : Unsteady flux values at T.S. point on Matthews for the first annual Cycle. At the top, calculations by the finite element method ; below, calculations by Heaviside 's series decomposition.

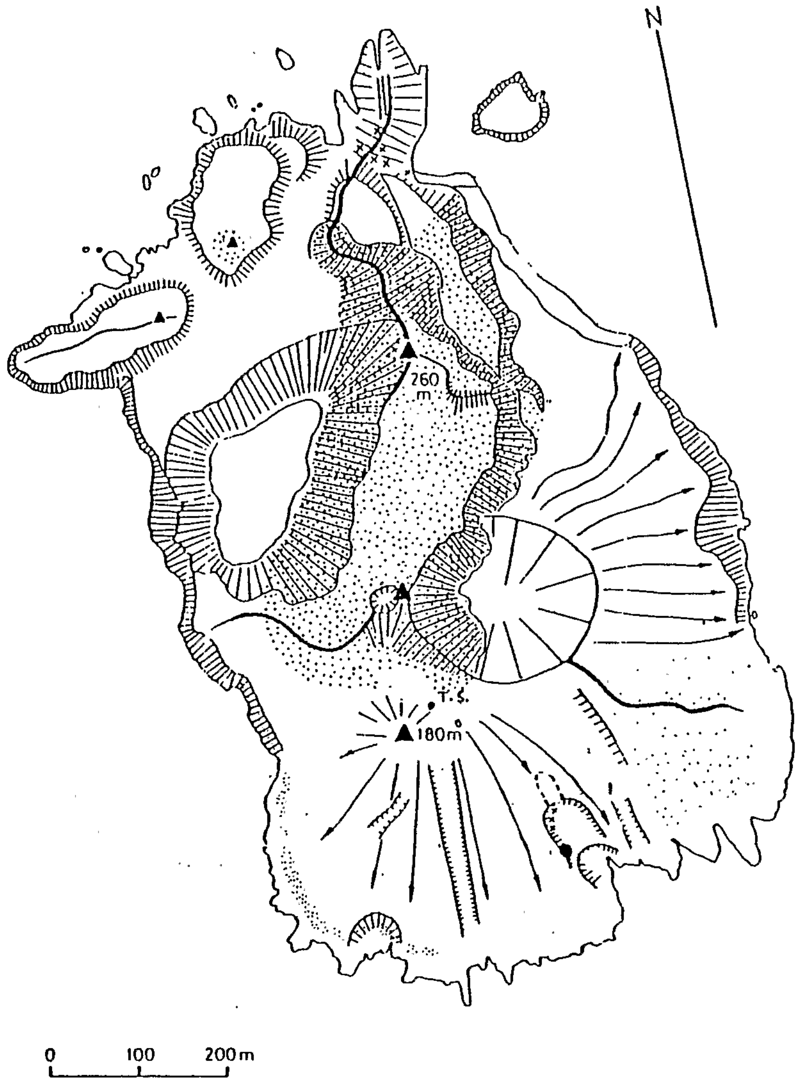

Fig. 3 : Map of Hunter volcano (after Monzier)

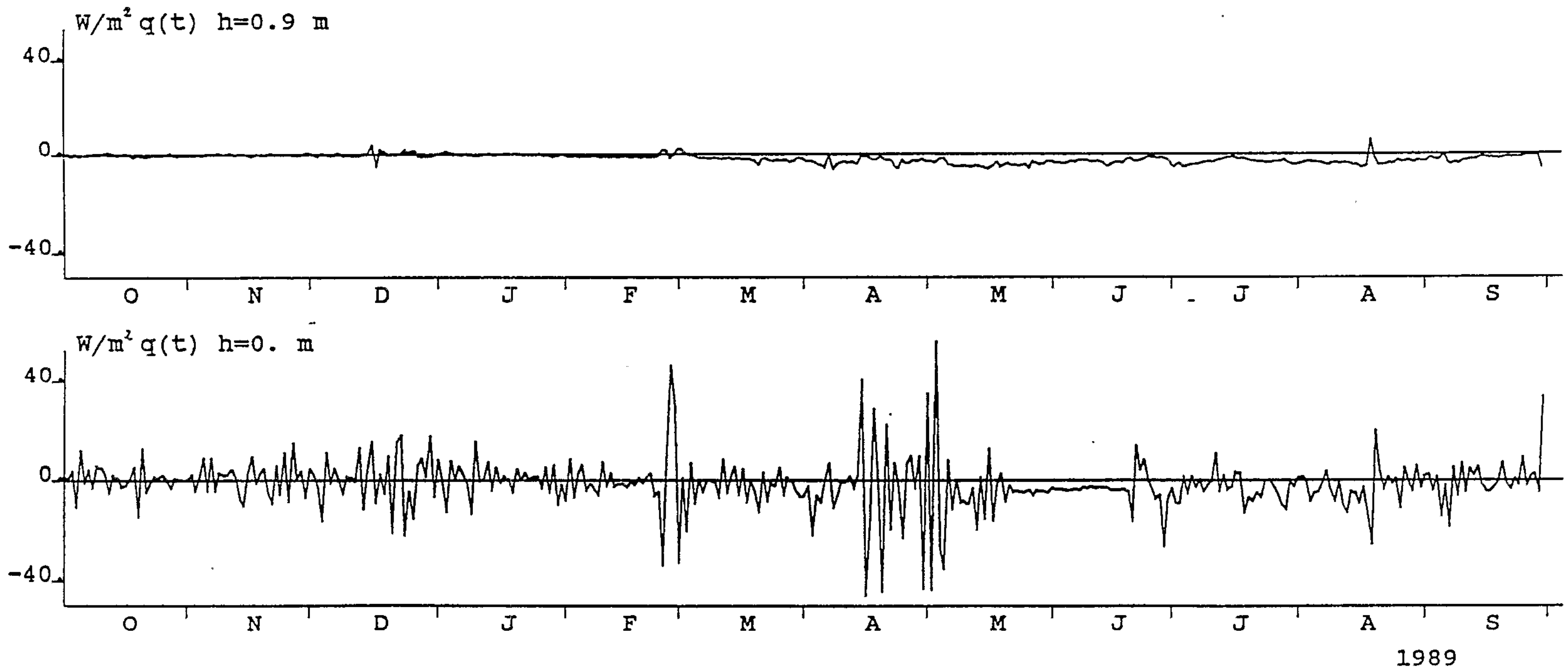

Figure 4 : Unsteady flux values at T.S. point on Hunter for the annual cycle.

HUNTER